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Title: Extremity Model for Neutron Dose Calculations

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Introduction

In personnel dosimetry for external radiation exposures, health physicists tend to focus on measurement of whole body dose, where "whole body" is generally regarded as the torso on which the dosimeter is placed.[1] Although a variety of scenarios exist in which workers must handle radioactive materials, whole body dose estimates may not be appropriate when assessing dose, particularly to the extremities. For example, consider sources used for instrument calibration. If such sources are in a contact geometry (e.g. held by fingers), an extremity dose estimate may be more relevant than a whole body dose. However, because questions arise regarding how that dose should be calculated, a detailed extremity model was constructed with the MCNP-4C[a] Monte Carlo code. Although initially intended for use with gamma sources, recent work by Shores[2] provided the impetus to test the model with neutrons.

Model Description

As dimensions of reference man's arms and hands are not specified in ICRP 23, measurements were taken of a typical hand and arm phantom[3] to approximate the length, width, and thickness of the upper extremity. The palm of the hand and the forearm were modeled as parallelpiped volumes while the fingers, thumb and bones were modeled as cylindrical volumes (Figure 1). The radii of the fingers ranged from 0.888 cm for the pinky to 0.938 cm for the thumb. The bones in each finger were separated by 0.03 cm thick discs of cartilage. All material compositions for the upper extremity, as well as densities, were taken from ICRP 23. The materials used in the model were cortical bone, yellow bone marrow, tissue, skeletal cartilage, the dermis and epidermis skin layers. Additional information may be found in recent work by Sattelberger.[4]

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[a] MCNP is trademark of the Regents of the University of California, Los Alamos National Laboratory

Methodology

Occupational exposure in the DOE complex is regulated via 10 CFR 835[5] and dose limits are specified for shallow dose equivalent (SDE) and deep dose equivalent (DDE). Because the reference depth for the specification of dose to the extremities is 70 μm (0.007 cm), shallow dose equivalent lends itself to calculation with MCNP4C[6] as it cannot be directly measured.

Like the earlier estimates of Shores, neutron dose equivalent rates were calculated for the following neutron sources: ^{238}PuBe, ^{239}PuBe, ^{241}AmBe, ^{241}AmLi, and ^{252}Cf. Each source was modeled as a 1-cm radius sphere with the center of the sphere located 1 cm from the palm of the hand (Figure 1). Regarding the source terms, neutron spectra, with the exception of the AmLi source, were generated with the SOURCES-3A computer code.[7] For the AmLi source, a tabular neutron spectrum in 40 keV intervals was obtained from Geiger and Van der Zwan.[8]

This work used MCNP's "F6" type energy deposition tally in conjunction with 10 CFR 835 neutron quality factors to convert absorbed dose (rad) to dose equivalent (rem). For the detailed extremity model, SDE was calculated by tallying over the region between the outermost epidermis skin layer and a depth of 0.007 cm in the epidermis and confiscated to the hand region only in an effort to closely approximate the simpler spherical model. True extremity dose, however, is measured at a depth of 70 m over the entire length of the extremity, from fingertip to base of the forearm.

By contrast, the simplified Shores model assumed the hand was a 1.5 cm thick spherical shell of NCRP 38 tissue placed around the source. The shell was divided into thin volume elements centered at 0.007 cm and 1.0 cm depths to tally for SDE and DDE, respectively.

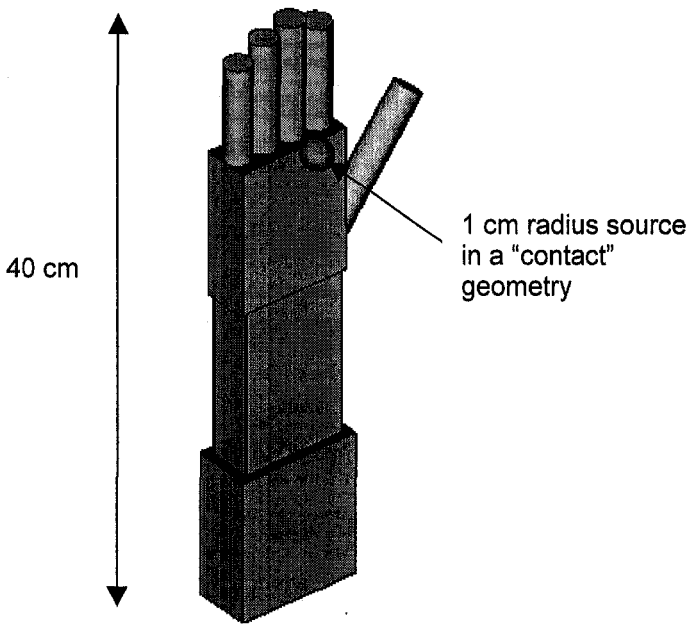

Figure 1. Source location relative to detailed extremity model

Results and Conclusions

Deep dose to the extremity is not a concern for radiation protection purposes, so a comparison of shallow dose was deemed more important in this study. Neutron shallow dose equivalent rates for several common neutron sources are presented in Table 1. The obvious trend for each case indicates the detailed hand model's SDE was roughly a factor of 30 lower than the simplified model. This difference is attributed to several factors. Because SDE was measured on both sides of the hand, the dose was averaged over the total epidermis volume and thus one would expect lower values. In addition, the spherical model's tissue volume was uniformly irradiated and designed to obtain a conservative estimate of SDE while approximating a contact geometry. Relative to the extremity model, however, the simple calculation does not adequately represent such a realistic contact scenario and the new extremity work appears to be superior. Although preparing such a detailed model isn't always practical, this work indicates

large variations in extremity dose estimates may occur. Further calculations, such as moving the source in different positions, would also be of interest.

Table 1. Shallow Dose Equivalent (SDE) Rates from a Contact Geometry

	Extremity Model	**Spherical Model**
Source	SDE (mrem/hr-Ci)	SDE (mrem/hr-Ci)
AmBe	1.13E+03	3.25E+04
AmLi	1.26E+01	4.26E+02
^{238}PuBe	1.19E+03	3.39E+04
^{239}Pube	8.70E+02	2.49E+04
^{252}Cf	1.99E+06	5.84E+07

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